Environmental Health Perspectives Supplements
Vol. 102 Suppl 1:187-193 1994

Human Milk as a Bioindicator for Body Burden of PCDDs, PCDFs, Organochlorine Pesticides, and PCBs

by Peter Fürst, Christiane Fürst, and Klaus Wilmers

In the State Laboratory of North Rhine-Westphalia for Food, Pharmaceutical and Environmental Chemistry (Chemisches Landesuntersuchungsamt), more than 600 individual human milk samples have been analyzed for polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), and more than 1400 individual milk samples have been analyzed for organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) since 1984. All samples were collected on a voluntary basis from nursing mothers mostly living in North Rhine Westphalia, a federal state in Germany. The samples analyzed so far show a typical pattern of PCDDs and PCDFs. Out of the 210 possible congeners, only those with 2,3,7,8-chlorine substitution were found. While OCDD normally shows the highest concentration, the levels of the other dioxin congeners decrease with decreasing number of chlorine atoms. A different pattern was found for PCDFs. Within this group 2,3,4,7,8-P_5CDF is the most abundant congener, followed by the hexachlorodibenzofurans. The mean level of tetrachlorodibenzodioxin (TCDD) was found to be of 3.2 pg/g on a fat basis and for total PCDDs and PCDFs, calculated as I-TEq (NATO/CMMS), 29.3 pg/g on a fat basis. The investigations of the past 2 years have revealed somewhat lower levels compared to former years. This might be an indication that the efforts undertaken to minimize dioxin emissions and to shut down known sources have already had an effect on the body burden of humans. Although mostly banned for a considerable period of time now, some lipophilic persistent pesticides such as DDT, dieldrin, hexachlorobenzene (HCB), and hexachlorocyclohexanes (HCH) can still be found in human milk. However, the levels of these residues have decreased during the past few years, indicating that the ban is having an effect. A similar trend was found for PCBs. Although their concentration in human milk was at the same level for a long period of time, a slight decrease was observed in the past 2 years. Although the tolerable daily intake concept, which is based on lifetime intake, should not be applied to the relative short nursing period, the results of human milk analyses are far above these levels. Despite the fact that no adverse health effects in babies could definitely be related to date to background levels of xenobiotics in human milk, it seems reasonable that all efforts should be undertaken to minimize the emission of these pollutants and to shut down known sources to achieve a reduction of the body burden of humans.

Introduction

Because humans are at the top of the food chain, it is obvious that human tissues may contain relative high amounts of those xenobiotics that tend to bioaccumulate within the food chain. The contamination of human milk with environmental pollutants and pesticides is of special concern because of its importance as the first food for the newborn child. As a special service, the North Rhine-Westphalian government offered to analyze nursing mothers' breast milk for organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and, since 1984, polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). To get an idea of the parameters that influence the levels of pollutants in human milk all women are asked to fill out a six-page questionnaire that contains queries concerning personal data of the mother, living conditions, food consumption, smoking habits, and use of cosmetics. A statistical evaluation of these data in combination with the analytical levels was presented at Dioxin '91 conference in North Carolina (*1*).

Analytical determination is performed using well-proven methods including high-resolution gas chromatography/high-resolution mass spectrometry (HRGC/HRMS). Quality control and quality assurance are ensured, *inter alia*, by participation in international quality control studies.

Results

PCDDs and PCDFs

Table 1 shows the results from the investigation of 526 individual human milk samples, including basic statistical data such as mean, median, minimum, and maximum levels and various percentiles. All milk samples analyzed so far only revealed the presence of 2,3,7,8-chlorine-substituted congeners. This

State Laboratory of North Rhine-Westphalia for Food, Pharmaceutical and Environmental Chemistry, Sperlichstr. 19, 4400 Münster, Germany.

Address reprint requests to P. Fürst, Chemisches Landesuntersuchungsamt NRW, Sperlichstr. 19, 4400 Münster, Germany.

Table 1. PCDDs and PCDFs in human milk, 1986–1991 ($n = 526$).

Compound	Levels in pg/g fat							
	Mean	Median	Minimum	Maximun	75%	90%	95%	99%
OctaCDD	207.9	181.0	40.0	738.0	257.0	337.0	399.0	551.0
1,2,3,4,6,7,8-HeptaCDD	41.2	37.0	8.0	143.0	50.0	67.0	78.4	107.0
1,2,3,4,7,8-HexaCDD	8.4	7.7	1.2	26.0	11.0	13.0	15.0	19.0
1,2,3,6,7,8-HexaCDD	35.8	33.0	5.6	95.0	44.0	56.0	61.0	80.0
1,2,3,7,8,9-HexaCDD	6.4	5.8	1.3	21.0	8.0	10.0	11.4	14.0
1,2,3,7,8-PentaCDD	10.1	9.6	1.7	28.0	12.0	15.0	17.0	24.0
2,3,7,8-TetraCDD	3.2	3.0	0.7	12.0	4.0	4.9	5.6	9.3
OctaCDF	1.4	1.0	0.2	14.0	1.5	2.4	3.3	7.3
1,2,3,4,6,7,8-HeptaCDF	5.5	4.6	0.5	53.0	6.7	9.2	11.0	20.0
1,2,3,4,7,8-HexaCDF	7.8	7.4	1.8	28.0	9.4	11.6	13.0	16.0
1,2,3,6,7,8-HexaCDF	6.5	6.0	1.6	16.0	8.0	9.8	11.0	14.0
2,3,4,6,7,8-HexaCDF	3.4	3.2	0.8	16.0	4.0	5.5	6.6	8.7
1,2,3,7,8-PentaCDF	0.5	0.4	0.1	5.0	0.6	0.8	0.9	1.8
2,3,4,7,8-PentaCDF	26.7	24.7	4.1	104.0	33.0	42.5	49.0	58.0
2,3,7,8-TetraCDF	1.7	1.5	0.2	7.7	2.3	3.0	3.5	4.5
I-TEq	29.3	27.7	5.6	87.1	35.8	43.9	48.1	62.6

Abbreviations: CDD, chlorodibenzo-*p*-dioxin; CDF, chlorodibenzofuran; TEq, toxic equivalent.

means that all congeners detected belong to the group of toxic PCDDs and PCDFs.

From octa- to tetrachlorodibenzo-*p*-dioxin, the levels in milk decrease with decreasing degree of chlorination. A somewhat different pattern is found for the chlorinated dibenzofurans. In this group, 2,3,4,7,8-P_5CDF is the predominant congener, followed by the three hexachlorodibenzofurans. In almost all cases OCDF was found to be present at only low concentrations.

A field study conducted by The World Health Organization Regional Office for Europe (WHO/EURO) showed that PCDD/PCDF levels in human milk from various industrialized countries of the Western world were very similar (*2*). An interesting exception is, however, that human milk samples from the United States contain significantly lower levels of 2,3,4,7,8-P_5CDF than specimens from Western Europe (*3*). The reason for this finding is still unknown. In view of the results from the WHO field study, it seems likely that the data from our series reflect the background contamination of milk from nursing mothers living in industrialized countries.

Frequency histograms are depicted in Figures 1–4. The graphs demonstrate that the levels for all congeners in question follow a lognormal distribution. The mean ratio of PCDF: PCDD is around 0.19, with a range of 0.06–0.40 (Fig. 5). A considerable deviation from this ratio might be an indication of a special exposure to PCDDs or PCDFs.

Figure 6 shows the share of each congener to the total PCDD and PCDF levels, expressed as pg/g fat and pg I-TEq/g fat, respectively. (I-TEqs are toxic equivalents calculated with international equivalency factors proposed by NATO/CCMS.) It can be clearly seen that OCDD amounts to 56.7% of the total PCDD/PCDF level but contributes only 0.7% to the total I-TEq value. The other extreme is 2,3,7,8-T_4CDD, which contributes an average share of 0.9% to the total PCDD/PCDF level but 11% to the toxic equivalents. The importance of 2,3,4,7,8-P_5CDF is demonstrated by the contribution of 45.6% to the total I-TEq level.

Figure 7 depicts the mean PCDD/PCDF levels expressed as I-TEq for each year the specimens were analyzed. Although the mean levels from 1987 to 1989 were similar, the analyses of the past 2 years showed a tendency toward lower levels. This decline is mainly due to lower levels for 2,3,4,7,8-P_5CDF, hexachlorodibenzo-*p*-dioxins, and 2,3,7,8-T_4CDF. Thus, it seems that efforts to reduce emissions are already effective to a certain extent. The investigation of future years will show if this trend remains constant.

Table 2. Average daily intake of PCDDs and PCDFs via human milk for a 5-kg baby.

	Intake, pg/kg body weight/day		
	Mean	Mininum	Maximum
2,3,7,8-T_4CDD	15.4	3.4	57.6
I-TEq	140.6	26.9	418.1

Abbreviations: PCDD, polychlorinated dibenzo-*p*-dioxin; PCDF, polychlorinated dibenzofuran; TEq, toxic equivalent.

Based on the analytical data (Table 1) and assuming a daily consumption of 800 mL milk with 3% fat, the average daily intake of PCDDs and PCDFs via human milk for a baby weighing 5 kg can be calculated (Table 2). These levels are far above all virtually safe doses (VSD) or tolerable daily intake (TDI) values proposed by health authorities in various countries, ranging from 0.006 (U.S. Environmental Protection Agency) to 10 (WHO) pg/kg/day. It must be mentioned, however, that the VSD and TDI concepts are based on lifetime intake and therefore should not be applied to the relative short period of nursing. On the other hand, the newborns may be expected to be more sensitive to toxic chemicals than are adults. Nevertheless, although no adverse health effects in a baby have been causally linked so far to background tissue concentrations of PCDDs and PCDFs, all efforts should be undertaken to reduce the emissions to levels as low as achievable and to shut down known sources wherever possible.

Organochlorine Pesticides and PCBs

All samples analyzed so far show a typical pattern of persistent lipophilic pesticides and PCBs. Table 3 depicts levels for the major compounds, separated by year of analysis. A calculation of a mean value for each pesticide over the entire time does not seem meaningful due to a permanent decline during the past few years (Fig. 8). This decrease is caused by a ban of most of these pesticides in the Western world after it was discovered that these substances are persistent and tend to accumulate within the food chain. The analytical data presented by time period demonstrate that actions taken in the early 1970s have had a beneficial effect on the body burden of humans.

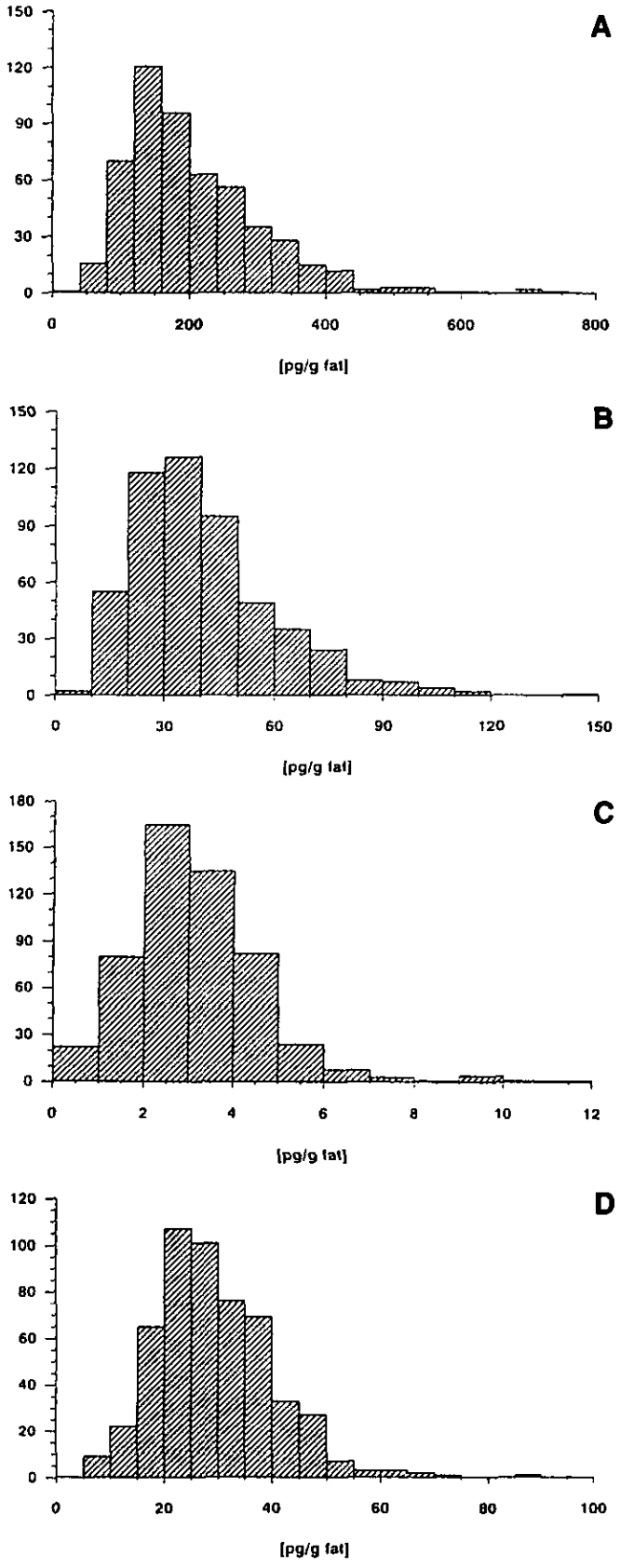


FIGURE 1. Frequency histogram for relevant PCDD/PCDF congeners in human milk. (*A*) Octachlorodibenzodioxin; (*B*) 1,2,3,4,6,7,8-heptachlorodibenzo-dioxin: (*C*) 2,3,7,8-tetrachlorodibenzo-*p*-dioxin; (*D*) I-TEq; n=526 for A–D.

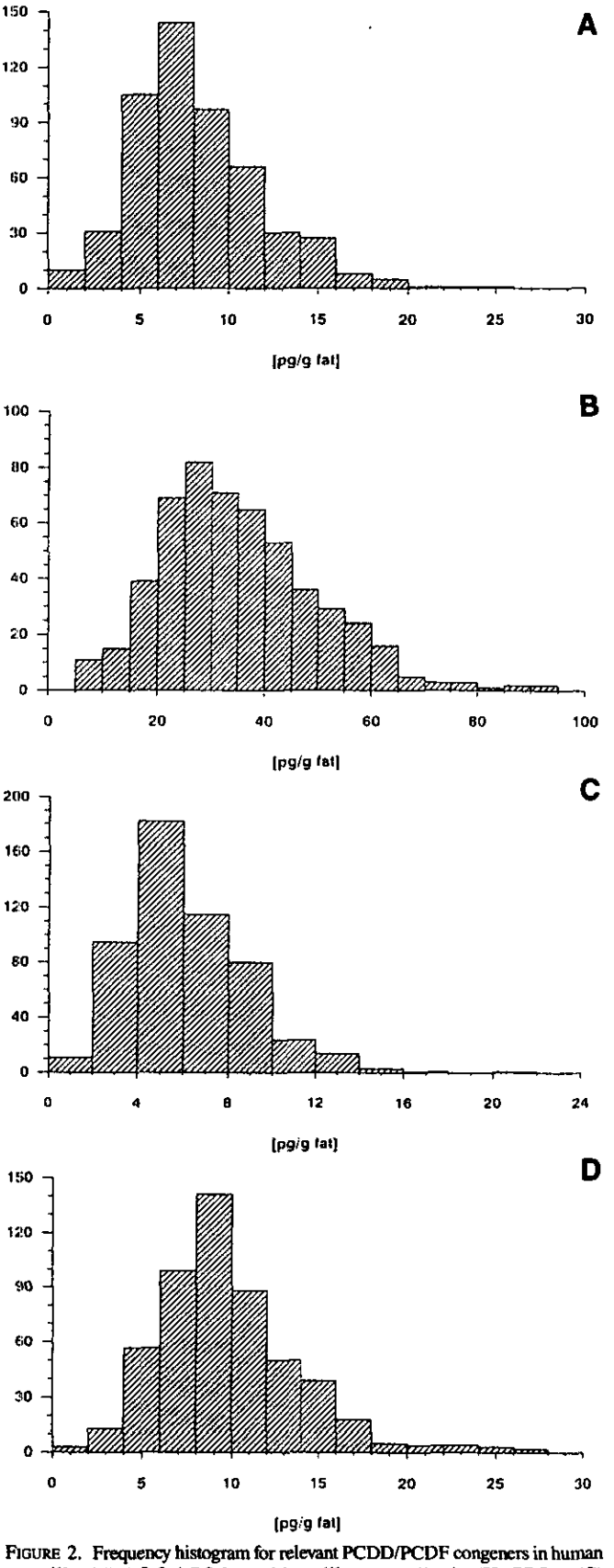
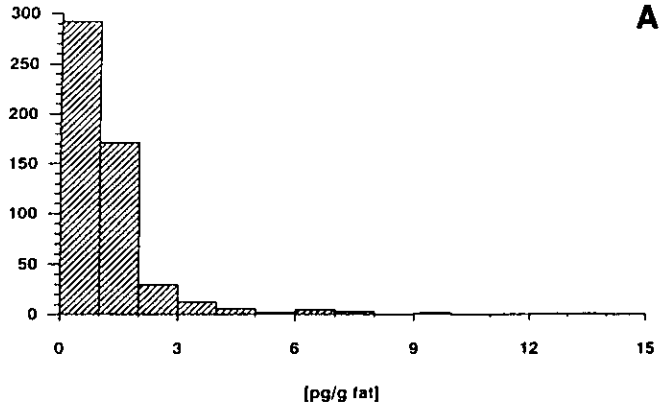
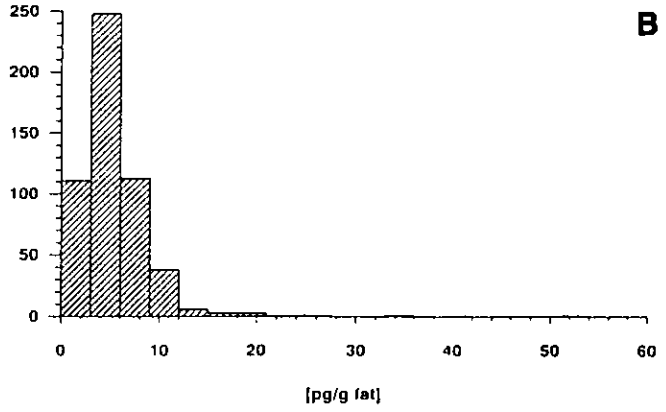
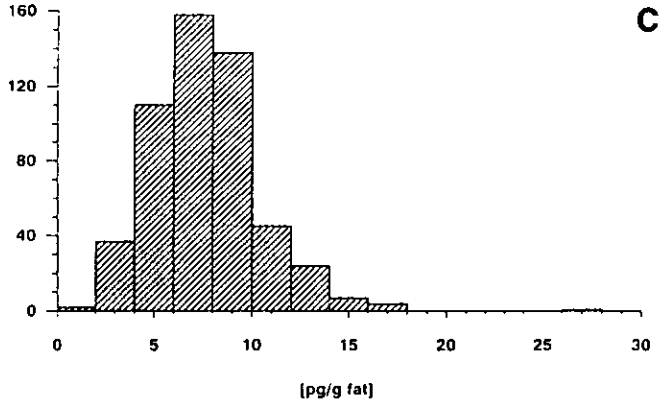


FIGURE 2. Frequency histogram for relevant PCDD/PCDF congeners in human milk. (*A*) 1,2,3,4,7,8-hexachlorodibenzo-*p*-dioxin (HxCDD); (*B*) 1,2,3,6,7,8-HxCDD; (*C*) 1,2,3,7,8,9-HxCDD; (*D*) 1,2,3,7,8-penta CDD. n=526 for A–D.







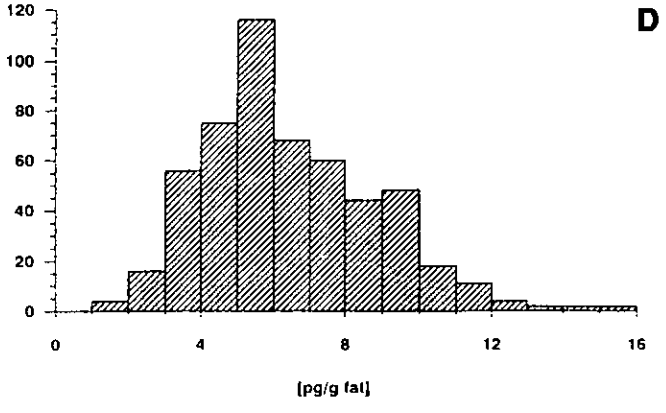
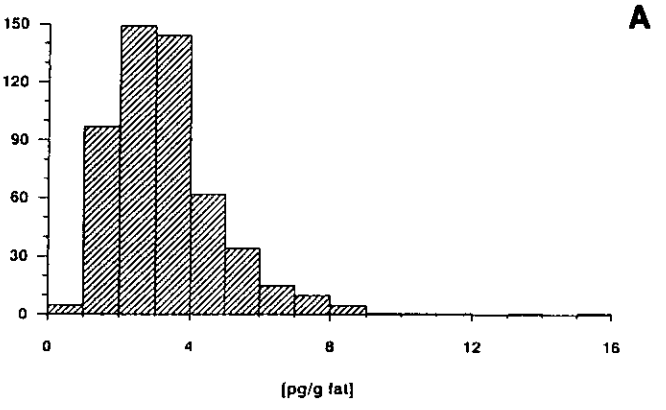
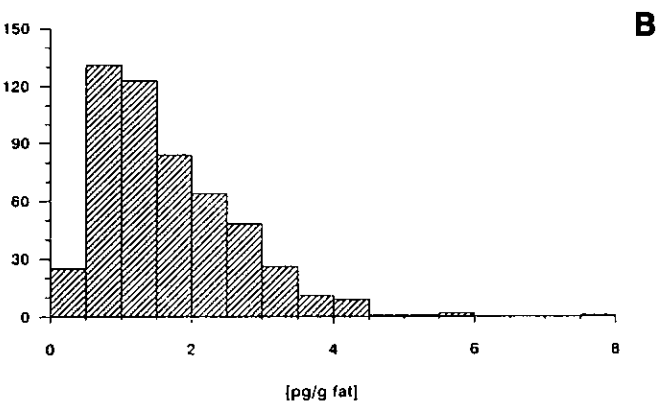
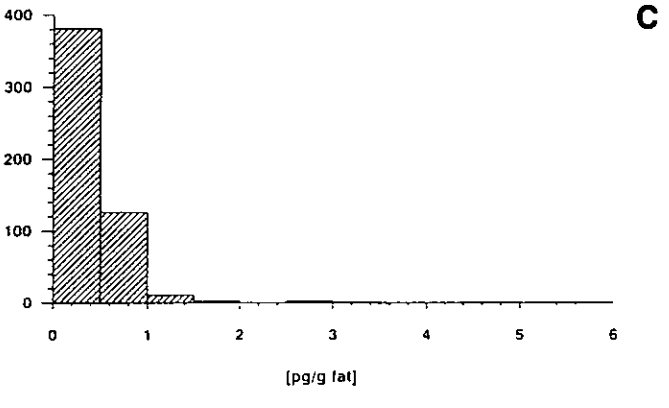


FIGURE 3. Frequency histogram for relevant PCDD/PCDF congeners in human milk. (*A*) Octadibenzofuran (OCDF); (*B*) 1,2,3,4,6,7,8 HpCDF; (*C*) 1,2,3,4,7,8 HxCDF; (*D*) 1,2,3,6,7,8 HxCDF. n=526 for A–D.







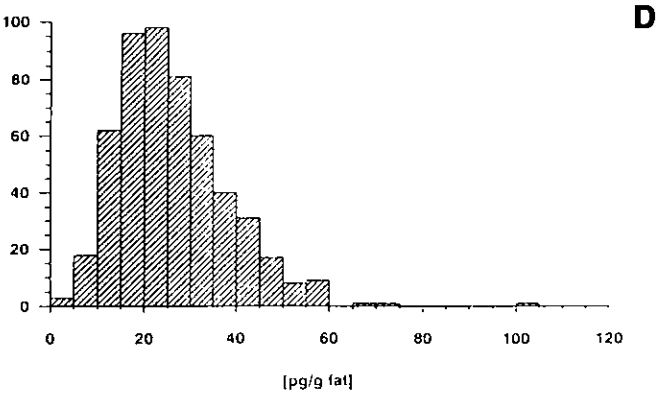


FIGURE 4. Frequency histogram for relevant PCDD/PCDF congeners in human milk. (*A*) 2,3,4,6,7,8-Hexadibenzofuran (HxCDF); (*B*) 2,3,7,8-TCDF; (*C*) 1,2,3,7,8 PeCDF; (*D*) 2,3,4,7,8-PeCDF. n=526 for A–D.

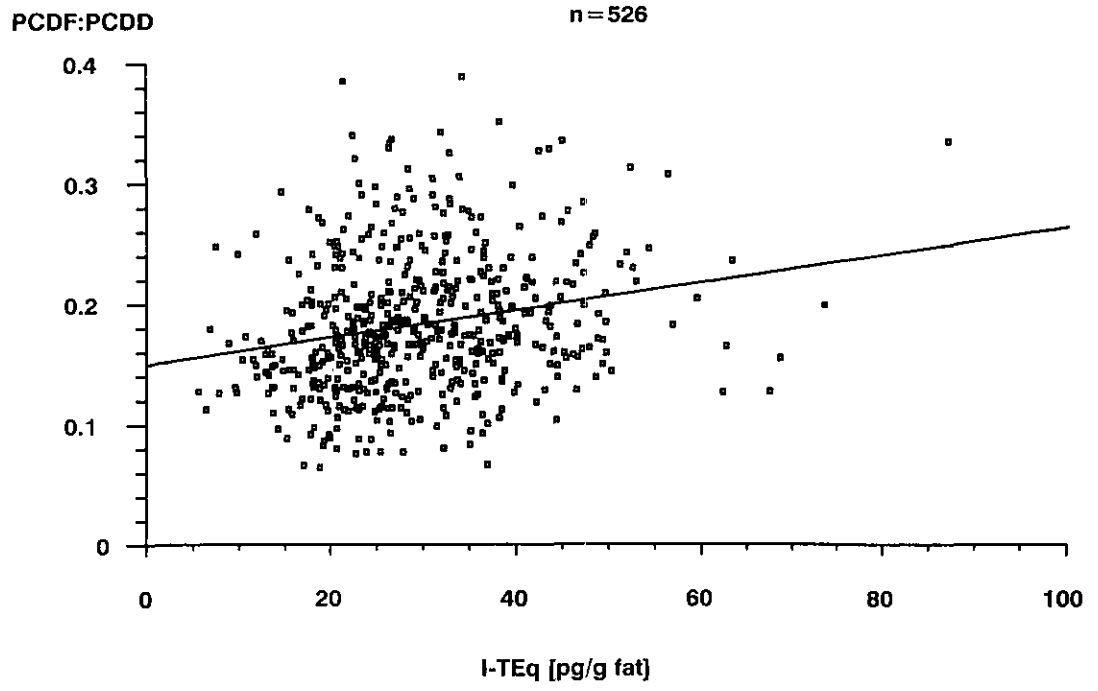


FIGURE 5. Ratio of PCDF: PCDD versus toxic equivalents (I-TEq) in human milk.

Table 3. OCP and PCB in human milk, 1984–1991 (n = 1405).

	Levels in ugly fat							
Compound	1984(144)[a]	1985(220)	1986(157)	1987(144)	1988(196)	1989(145)	1990(286)	1991(113)
HCB	0.511	0.463	0.361	0.354	0.316	0.246	0.227	0.177
β-HCH	0.130	0.122	0.112	0.092	0.076	0.079	0.064	0.056
γ-HCH	0.021	0.020	0.021	0.020	0.015	0.016	0.008	0.006
pp-DDE	0.893	0.836	0.718	0.755	0.637	0.659	0.534	0.504
pp-DDT	0.085	0.086	0.053	0.051	0.038	0.044	0.027	0.027
Dieldrin	0.022	0.021	0.014	0.015	0.018	0.015	0.011	0.009
PCB #153	0.362	0.356	0.324	0.327	0.324	0.296	0.253	0.254
PCB #138	0.252	0.268	0.269	0.256	0.240	0.235	0.202	0.202
PCB #180	0.156	0.165	0.157	0.172	0.197	0.180	0.124	0.125

Abbreviations: OCP, organochlorine pesticide; PCB, polychlorinated biphenyl; HCH, hexachlorocyclohexane; DDE, major DDT metabolite.
[a]Number of samples analyzed.

A similar trend, although somewhat more gradual, can be observed for PCBs. Although human levels of these contaminants were almost constant over a long period of time, the analyses of the last 2 years indicate a slight decline. The sum of PCBs in Figure 8 was calculated as (PCB #138 + #153 + #180) *1.64.

A statistical evaluation of OCP and PCB versus dioxins and furans revealed relative high coefficients of correlation for PCDDs/PCDFs with PCB and PCDDs/PCDFs with HCB, respectively (Figs. 9 and 10). This finding suggests some common sources, such as food, which was found to be the main route of exposure, at least to PCDDs and PCDFs (*4-6*).

A risk assessment for the breastfed baby can best be performed by comparison of the actual daily intake in relation to the no observed effect level (NOEL) derived from animal experiments. Based on the OCP and PCB levels in 1990 the following ratios of NOEL versus actual daily intake (shown in Table 4) result.

As can be seen for most pesticides in question, the factor exceeds 100, a value that is often used as safety factor for derivation of TDI values. On the other hand, it may create potential health effects if the factor is below 10, which happened in some cases for PCBs. As already mentioned for PCDDs and PCDFs, however, the TDI concept and NOEL values are both based on a lifetime intake and therefore should not be used for the relative short nursing period. Nevertheless, if a factor for a compound is less than 10 in relation to the NOEL we recommend that the mother reduce her amount of breast milk until at least a factor of 10 is reached. Fortunately, this problem occurs only rarely.

Table 4. Ratios of NOEL versus actual daily intake.

Compound	NOEL, mg/kg	NOEL/daily intake
Hexachlorobenzene	0.06	47
β-HCH	0.50	279
γ-HCH	1.00	22321
total DDT	0.50	159
Total PCBs	0.10	19

Abbreviations: NOEL, no-observed effect level; HCH, hexachlorocyclohexane; PCB, polychlorinated biphenyl.

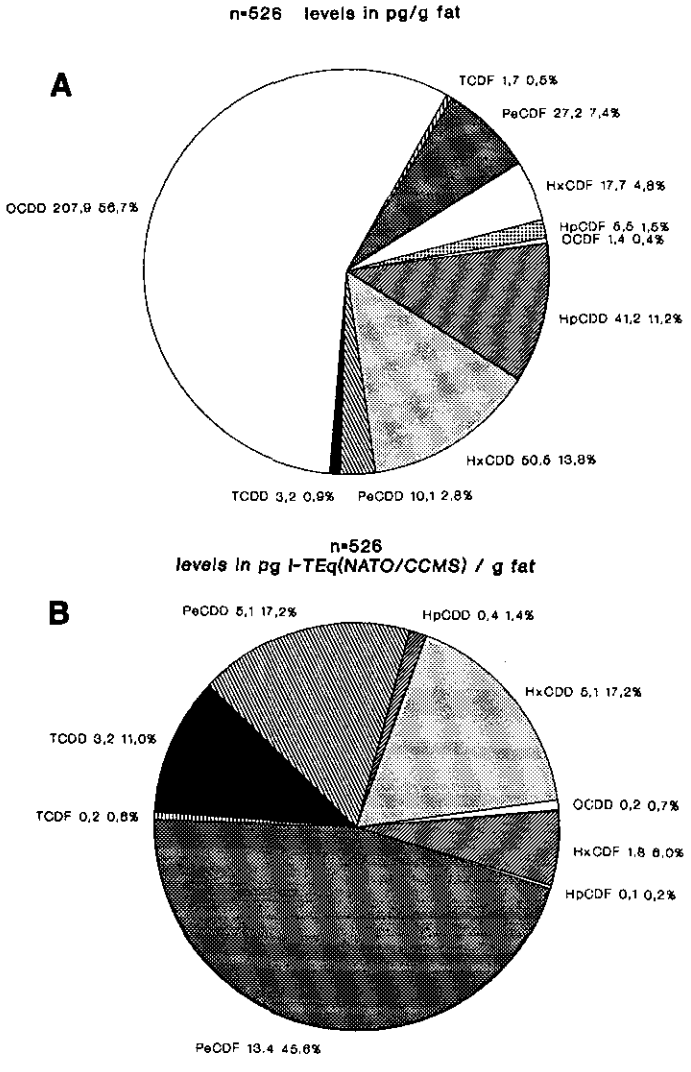


FIGURE 6. Share of various congeners to the total PCDD/PCDF level in human milk. (*A*) Levels expressed as pg/g fat; (*B*) levels expressed as pg I-TEq/g fat. $n=526$.

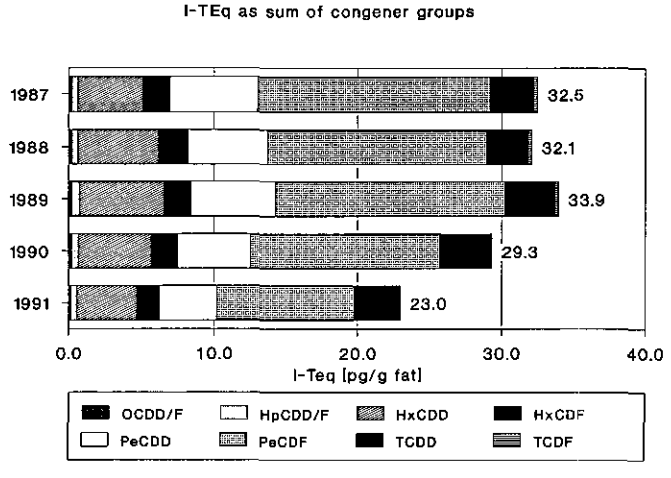


FIGURE 7. PCDDs/PCDFs in human milk, time trend 1987–1991; I-TEq as sum of congener groups.

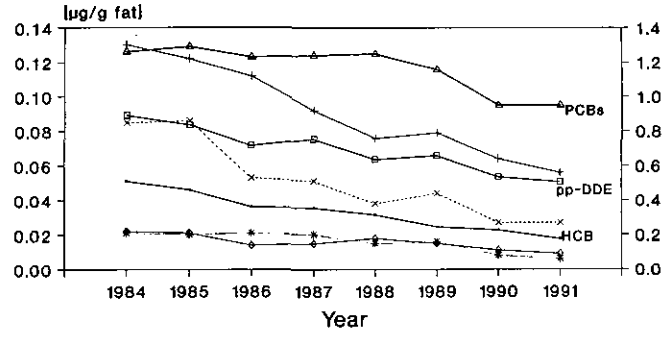


FIGURE 8. Organochlorine pesticides and PCBs in human milk, time trend 1984–1991: (—●—) hexachlorobenzene (level on right axis); (—+—) β-HCH; (∗) γ-HCH; (—⊟—) *pp*-DDE (level on right axis); (—x—) *pp*-DDT; (—◇—) dieldrin; (—△—) sum of PCBs (level on right axis).

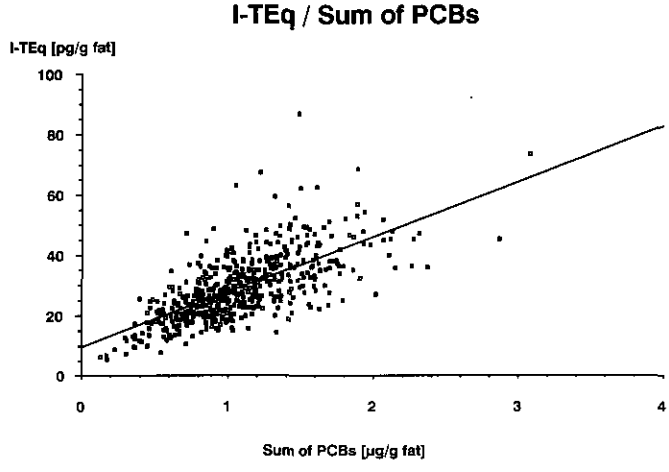


FIGURE 9. Correlation of PCDD/PCDF (I-TEq) versus PCB s in human milk.

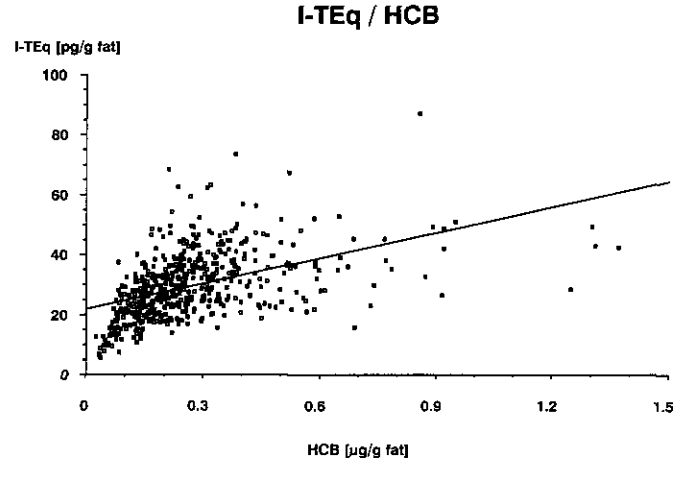


FIGURE 10. Correlation of PCDD/PCDF (I-TEq) versus HCB in human milk.

The authors are grateful to Arnold Schecter, State University of New York, for fruitful discussions and for critically reviewing the manuscript.

REFERENCES

1. Fürst, P., Fürst, C., and Wilmers, K. PCDDs, PCDFs, organochlorine pesticides and PCBs in human milk—statistical evaluation of a 6 year survey. Chemosphere 25: 1029–1038 (1992).
2. WHO/EURO. Levels of PCBs, PCDDs and PCDFs in Breast Milk. Environmental Health Series, Vol. 34, World Health Organization, Copenhagen, 1989.
3. Schecter, A., Fürst, P., Krüger, C., Meemken, H. A., Groebel, W., and Constable, J. D. Levels of polychlorinated dibenzofurans, dibenzodioxins, PCBs, DDT, and DDE, HCB, dieldrin, HCHs and oxychlordane in human breast milk from the United States, Thailand, Vietnam and Germany. Chemosphere 18: 445–454 (1989).
4. Beck, H., Eckart, K., Mathar, W., and Wittkowski, R. PCDD and PCDF body burden from food intake in the Federal Republic of Germany. Chemosphere 18: 417–424 (1989).
5. Fürst, P., Fürst, C., and Groebel, W. Levels of PCDDs and PCDFs in food stuffs from the Federal Republic of Germany. Chemosphere 20: 787–792 (1990).
6. Birmingham, B., Thorpe, B., Frank, R., Clemont, R., Tosine, H., Fleming, G., Asham, J., Wheeler, B., Ripley, D., and Ryan, J.J. Dietary intake from food in Ontario, Canada. Chemosphere 19: 507–512 (1989).